The Use of Undergraduate Minors to Meet National Needs in Nuclear Fission Power Engineering

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Abstract:

With the renewed interest in nuclear power as a key component of the nation's energy portfolio, there is a growing concern about the availability of engineers trained in nuclear technology in view of the very significant erosion in university nuclear engineering programs and facilities over the past two decades. Even with a rapid infusion of new resources, the time required to rebuild the necessary faculties and facilities and stimulate student interest makes it highly unlikely that conventional nuclear engineering programs can provide a flow of graduates adequate to meet the near-term needs of industry and the federal government.

As an alternative, we have explored the development of a national curriculum in nuclear fission power engineering that would serve as a certificate-based, minor concentration for undergraduate students majoring in traditional engineering degree programs such as mechanical, electrical, chemical, and materials science engineering The proposed program would augment conventional undergraduate engineering degree programs with a 4-5 course sequence offered in the junior and senior years, accompanied by a summer practicum involving extensive laboratory experience at a regional university reactor facility, a national laboratory, or an industrial site. The proposed nuclear-power minor curriculum would be supported by extensive computer and network resources, including nuclear code simulation packages, web portals, and technology-enhanced learning for on-campus and off-campus distance education.

Through extensive surveys conducted by the University of Wisconsin, we have established strong interest in such programs on the part of industry, government, and prospective students. Industry representatives have expressed interest in hiring nuclear engineers more broadly trained in general engineering majors, while many students view such a nuclear power minor concentration as a more attractive alternative to a specialized nuclear engineering major. Since the proposed program would be highly transportable, drawing its content from faculty members at nuclear engineering programs across the nation and subsidized, in part, by industry and the federal government, it would broaden considerably the number of institutions capable of offering instruction in nuclear fission power engineering.

The paradigm of certificate-credentialed minor concentrations could serve as a useful model in engineering education for addressing the needs for engineers trained in other highly specialized areas such as power systems engineering, integrated manufacturing, nanotechnology, quantum engineering, and biomedical engineering. An undergraduate minor concentration appended to a more traditional curriculum would allow students to prepare for careers in such fields without sacrificing the broader educational experience and employment opportunities provided by a more

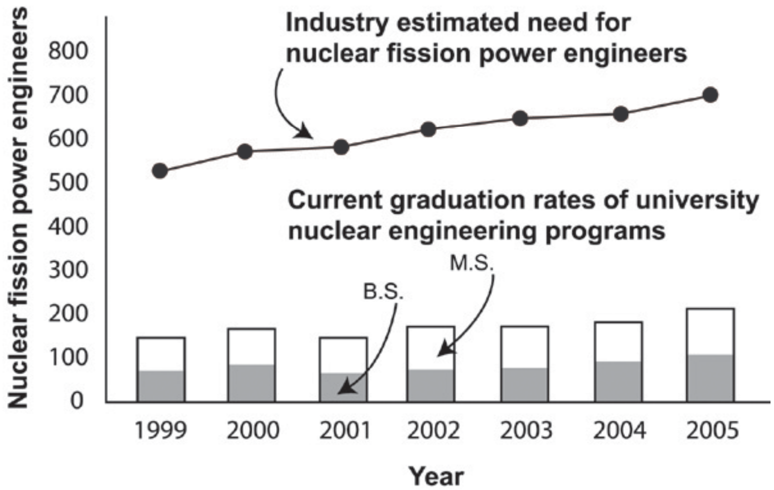
conventional degree program. Furthermore, by developing a curriculum and supporting resources for a minor concentration using a team of national leaders in the given specialty, colleges and universities could offer such specialized curricula without significant additional investments in new faculty and facilities. In fact, the model we have explored could well represent the future of engineering education as technical knowledge continues to fragment into subdisciplinary specialties, and universities face growing constraints on resources.

The Need

There has been growing anxiety about the future of this nation's capability in nuclear fission technology even as renewed interest in nuclear power has been stimulated by concerns about the impact of fossil fuels on global climate change, the growing imbalance between energy supply and demand, both regionally (e.g., California) and in the developing world, and other nuclear technology-related issues including the proliferation of nuclear weapons technology and materials and the disposal of radioactive waste. As Vice President Cheney stated in outlining the nation's new energy strategy on April 30, 2001, "If we are serious about environmental protection, then we must seriously question the wisdom of backing away from nuclear power, which is, as a matter of record, a safe, clean, and very plentiful energy source."

Yet we face a growing crisis in the availability of scientists and engineers trained in nuclear technology. Numerous studies conducted by industry, higher education, and the federal government have come to the conclusion that the current supply of graduates trained in nuclear engineering cannot keep up with the growing needs of the nuclear industry. In fact, even without further growth in the number of nuclear power plants and other facilities in the United States, the approaching retirements of an aging work force combined with low enrollments in nuclear engineering programs in most colleges and universities raise concern about a looming crisis.[1]

Over the past decade the number of nuclear engineering programs in the United States has declined by half (from 80 to 40), the number of university research and training reactors by two-thirds (from 76 to 28), and enrollments have dropped by almost 60% (from 3,440 to 1,520). As noted in a recent planning study by the Department of Energy's Nuclear Energy Research Advisory Committee: "Nuclear engineering programs in the United States are disappearing. Without concerted action by the federal government, most of the existing nuclear engineering programs will soon evaporate or be absorbed and diffused into other engineering disciplines."[2]



On the other hand, the demand for nuclear-trained personnel is again on the rise. Workforce requirements at operating U.S. nuclear power plants are increasing and will undoubtedly remain high, given the plans for plant-life extension in the vast majority (85%) of operating light-water reactors in the U.S.[3] A study conducted by Navigant Consultant for the Nuclear Energy Institute concluded that approximately 90,000 new nuclear professionals would be needed over the next decade in the United States. More specifically, the study identified the need for approximately 2,400 new nuclear engineers and 1,300 health physicists over this period. In addition, there is a continued growth of nuclear power in the Pacific Rim and continued advances in the design of a future generation of nuclear fission reactors (particularly the new Generation IV reactor concepts[4]). Moreover, new initiatives have appeared in applied radiation sciences in collaboration with industrial and medical researchers. Finally, nuclear science and engineering (NS&E) continues to be needed in national defense and includes technology related to arms reduction and verification and enforcement of international treaties. Thus, the future of nuclear science and engineering university programs must be reevaluated and refocused as the new century begins.

Yet, even if substantial re-investment in nuclear energy R&D and academic nuclear engineering programs were to occur, it is unlikely that in the near term the nation would be able to close the growing gap between the growing needs of industry and the federal government for engineers and scientists trained in nuclear fission technology and the capacity of our university's nuclear engineering programs. It will take a decade or more to produce the next generation of faculty capable of handling expanded enrollments. Furthermore, in spite of the strong market for nuclear engineering graduates, students are still reluctant to enter this field because of uncertainty about its future. As a stopgap measure, the nuclear power industry in the United States and several other nations is attempting to train engineering professionals from other fields on-site, but this has proven to be costly and not as effective as an integrated university educational program.

The Approach

Recognizing the resource constraints on conventional nuclear engineering degree programs, we have explored the potential of an alternative that we believe is capable of rapidly restoring the flow of engineers and scientists trained in nuclear fission power technology: a certificate program in nuclear fission power engineering, developed by a national consortium of universities and faculty, that could be added as an academic program concentration “minor” to any conventional undergraduate engineering degree program as well as selected science majors (e.g., physics and chemistry).This multiple-course nuclear power curriculum would include a summer practicum involving extensive laboratory experience (perhaps at a regional university reactor facility or a national laboratory) taken between the junior and senior years of the undergraduate major. The proposed nuclear power curriculum would be supported by extensive computer and network resources, including nuclear code simulation packages, web portals, and technology enhanced learning for on-campus and off-campus distance education. We have explored the possibility of forming a team of faculty members drawn from a number of the leading nuclear engineering programs in the nation to develop a curriculum sequence in nuclear fission technology. We have also begun discussions with the nuclear power industry seeking their participation in both the development and certification of this curriculum.

We believe that such a program has the potential for rapidly expanding the production of engineers and scientists capable of contributing to our nation’s nuclear energy programs since it would draw from the large cadre of engineering and science majors rather than the small enrollments of nuclear engineering degree programs. In fact, industry has long expressed interest in hiring nuclear engineers more broadly trained in general engineering majors such as mechanical engineering, electrical engineering, and computer engineering. Furthermore, this approach is particularly attractive to universities since it would allow them to respond to growing national needs in nuclear energy without the necessity of major expansion of existing nuclear engineering faculty or facilities (unlikely in the current budget climate in any event). The program would be designed to be highly transportable, and since both the content and support of the proposed program would be provided by a team of faculty members drawn from top nuclear engineering programs across the nation, individual institutions would not have to commit additional resources to build new capabilities.

A collateral benefit of this program is that it would lead to an increase in graduate student enrollment in nuclear engineering. While admissions requirements vary among institutions, students who have successfully completed the proposed certificate program would have prerequisites and possibly the interest to continue on at the graduate level in nuclear engineering programs, with little disadvantage compared to undergraduates with baccalaureate degrees in nuclear engineering.

Finally, such a program might be far more attractive to students because of its flexibility. Their traditional engineering (or science) degree would give them the full spectrum of career opportunities, while the nuclear power minor would qualify them to enter nuclear technology careers, should they so choose. Since the nuclear power curriculum would be designed to be compatible with the technical and general electives available in most engineering and science programs, students would be able to add this option to their existing major with minimal sacrifice in time-to-degree.

The basic curriculum model is straightforward: a 15 credit hour program, with four 3-credit-hour courses taken in each semester of the junior and senior year, augmented by a summer internship and/or laboratory experience (worth an additional 3 credit hours).

Junior year: Atomic and nuclear physics
Nuclear reactor physics

Summer Term: Internship in nuclear industry or national lab
(Alternative: laboratory in nuclear measurements and reactors)

Senior year: Nuclear energy systems (including power plants and fuel cycle)
Radiological science (including dosimetry and shielding)

Note that this curriculum compares to 30 credit hours (with significant prerequisites and cognate curriculum requirements in areas such as physics and mathematics) for the traditional nuclear engineering baccalaureate degree.[5]

The summer experience between the junior and senior year is a particularly important component of this curriculum. While one approach would be to include the laboratory courses during the summer term, we must also keep in mind that most students seek to earn income even as they acquire engineering experience through summer employment. Hence we believe it best to view the summer experience as an employed and structured internship or practicum in nuclear energy with a nuclear energy company or national laboratory, a view supported by student focus groups. (This seems compatible with current practice since many companies seek to use such "co-operative employment" to assess and recruit future employees, and most national laboratories have summer positions for engineering students.)
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The market assessment process below suggests that the nuclear fission power engineering minor would be most compatible with engineering majors such as mechanical engineering, materials science engineering, electrical engineering, and chemical engineering. However we can also imagine the possibility of combining this with aerospace engineering (particularly with NASA's recent interest in space nuclear energy systems and nuclear propulsion as a requirement for manned missions beyond the moon), civil engineering (to prepare engineers for architect-engineering firms), environmental engineering, and systems engineering.

Market Assessment

Working with the University of Wisconsin Survey Center, we arranged for a series of market surveys to assess: i) the interests and curriculum preferences of prospective employers, including electrical utilities, nuclear equipment vendors, national laboratories, and other federal agencies; and ii) the attractiveness of such a minor concentration to potential students.

The Views of Employers

The assessment of industry views involved 15 structured interviews of senior executives in firms or national laboratories that recruit nuclear engineers. Most of these organizations commented on the decreasing availability of nuclear engineers. In fact two noted that because of this shortage, they had stopped trying to recruit nuclear engineers and now targeted other engineering disciplines that might be trained inhouse for nuclear roles. One executive reinforced this view by noting, "Availability of nuclear engineers is limited right now and has been decreasing. Since it is much easier to find mechanical and electrical engineers, we are now targeting these disciplines and trying to bring them up to speed." The issue here is that the nuclear engineering educational community is not playing a part in bringing these non-nuclear engineers “up to speed” and this initiative addresses this concern.

There was a very positive response to the proposed minor concentration. Most respondents said they would certainly consider hiring an engineering graduate with the minor in nuclear engineering. Typical quotes were:

- "We would absolutely hire these graduates."
- "We would favor the combination of an engineering major with a minor in nuclear engineering for certain positions such as nuclear reactor safety."
- " A mechanical or electrical engineer with a nuclear minor might be well suited for managerial roles."
- "We would be particularly interested in mechanical or materials engineers with a nuclear engineering minor."

Here it should be noted that while the employers were enthusiastic about engineers with a nuclear engineering minor, they were less enthusiastic about physics majors with such a concentration, and rather negative about mathematics majors with such a concentration. They believed that an engineering degree was far preferable.

A quote from a senior executive at one of the largest nuclear utilities summarized these views: "The industry needs today are mostly for non-nuclear engineers with some nuclear background. The ideal would be some mechanism whereby non-nuclear engineering candidates in the course of obtaining their degrees could take some nuclear course work and upon graduation have familiarity with the field. This would enhance the student's job prospects."

Most employers were comfortable with the proposed topic areas for the minor: nuclear and reactor physics and laboratory: radiation detection, measurement, and shielding; nuclear systems; and economic and environmental issues in nuclear power. All were very enthusiastic about the possibility of an internship or practicum experience, and several suggested that their companies might be willing to participate in co-operative programs in this area.

Essentially all of the respondents stated that they felt this minor would be very beneficial, although they recognized that it would not completely replace or reduce emphasis on nuclear engineering as a major.

The Views of Prospective Students

Four student focus groups were formed to understand better the factors that motivate students' choice of major and how they would respond to the nuclear fission power engineering minor. High on all of the students' lists of factors considered in choosing a major were the perception of the job market, the flexibility of the major (allowing them to pursue various interests), and the marketability of the major in more than one area. Several mentioned they had selected a major (e.g., mechanical or electrical engineering) because of its perceived breadth and flexibility.

Most of these students in these focus groups had negative images of nuclear engineering as a major or career. Their impression was that nuclear engineering was a field in decline, with low demand for nuclear engineers, and few career opportunities. (They were surprised to learn of the current market demand, but worried that it might be temporary.) They also viewed a nuclear engineering major as particularly demanding, consisting of highly technical and difficult courses.

Most students reacted very positively to the possibility of a minor concentration–provided that it would not overly extend their time to degree. Attractive features were a potential enhanced marketability with such a certificate program, gaining the certificate without much additional time in school, increased salary potential, and more career options to explore. Typical quotes were:

- "It would open another door. It would allow us to have our chemical or mechanical engineering degree but at the same time we would still have a security of a safety net if the nuclear concentration did not work out."
- "It makes you more marketable. It is something that would give you an edge over other people when applying for a job."
- "If it is something you can do in a couple of semesters, then it would be a lot more appealing to more people than just the nuclear engineering major."

Students were particularly interested in the possibility of a summer internship, although far less enthusiastic about spending the summer in laboratory courses (which would not only be academically demanding but probably require them to forego much-needed summer employment income). For the most part, the juniors and seniors in the focus group felt their programs were flexible enough to incorporate plans for the minor after the beginning of their sophomore year.

Almost all of the participants in the focus groups said that they would be interested in more information about the proposed minor, if it were available.

Institutional Markets

We can identify three possible markets for these programs:

1. Offering minors within engineering/science schools that already have a nuclear engineering program giving baccalaureate degrees. (Note this might also be interpreted as a dual major for these institutions.) This could have a negative impact on nuclear engineering enrollments if students felt this would provide a “safety net” and still allow them to elect nuclear engineering.

2. Offering minors to universities with strong engineering programs which do not offer nuclear engineering degrees. (This might only require an articulation agreement for acceptance of credits from another institution offering the minor courses–a framework

that already exists for some institutions such as the Committee for Institution Cooperation (C.I.C.) for the Big Ten universities, for example.)

3. Offer minors to colleges and universities with modest science and engineering programs (regional universities, predominantly minority institutions, liberal arts colleges).

Of course there would be considerable difference in how the minor concentration would be designed, delivered, and financed for each of these market segments.

Certification

Although we considered the use of standard accreditation bodies such as ABET or EIS to certify the minor concentration, in the end we believe this might prove to be too cumbersome. Such a formal accreditation process is more appropriate with baccalaureate engineering degree programs rather than minor concentrations.

Instead we became convinced that the certificate process would be most valuable to students and industry if it were subject to an industry-based certification process. After consultation with industry and government leaders, we recommend the formation of a standing advisory panel from the employer market (industry, government) to monitor the program, provide industry perspective, and, in the end, provide certification.

The Design Elements

There are some unique aspects to nuclear engineering education that should be considered in developing such a curriculum. First, nuclear engineering is almost unique among the engineering disciplines in its multiscale nature, spanning the range from microscopic nuclear and atomic physics to macroscopic systems engineering. Second, it differs conceptually from many engineering disciplines in its statistical approach to the description of underlying physical processes such as neutron diffusion and fission chain reactions. (Whereas mechanical engineers view objects as solid, nuclear engineers view all matter as "porous", at least to ionizing radiation!)

Finally, and perhaps most important, large-scale computer simulation plays an essential role in nuclear engineering. Indeed, the earliest computers (ENIAC) were developed to analyze nuclear systems, and nuclear engineering continues to be one of the most computationally demanding disciplines. It is essential that any curriculum not only develop in students the ability to utilize large-scale computer programs or "codes" in the analysis and design of nuclear systems, but further expose them to the general features of current practice in this area.

Hence, to be successful in designing, developing, propagating, and supporting such a national curriculum, one will need support from multiple sponsors both within the federal government and industry for a number of activities:

- Designing, developing, implementing, and assessing the nuclear power curriculum
- Developing the supporting resources include computer code simulators ,web support, and distance learning technology

- Negotiating sites (universities, national laboratories, nuclear industry, and possibly foreign sites) for summer laboratory/practicum programs
- Seeking industry participation in curriculum development and certification for the program. (We already have some experience working with industry to develop both curriculum and summer experiences at industry sites in specific areas such as nuclear reactor safety.)

Fortunately, the infrastructure for such web-based instruction is evolving rapidly through efforts such as MIT's OpenSourceWare program, large-scale university software archives such as DSpace, and instructional software standards efforts such as the Open Knowledge Initiative. The development of the nuclear power certificate program should take advantage of these resources.

Funding Models

As with any new curriculum effort, sustainable funding mechanisms are essential. Although it seems apparent that for the long term, expanding the pool of engineers trained for the nuclear energy industry through augmenting conventional engineering degrees with a minor concentration in nuclear fission power engineering will be less expensive than adding the additional faculty, laboratories, and other resources to dramatically expand existing nuclear engineering programs, the proposed certificate program will require new resources, at least during the startup phase. For example, the students participating in the summer internships will require living support and compensation (although if this is accomplished through existing summer programs in industry and national laboratories, the incremental costs should be modest). Furthermore, the curriculum development effort will require some investment for faculty involvement and support staff.

It is our belief that the funds necessary to launch this program should come from a combination of federal and industry support, since this effort is designed to respond to the national needs of these sectors. More specifically, we believe that since the U.S. Department of Energy has been assigned the lead responsibility for developing and sustaining the human resources necessary for nuclear energy development and implementation in this nation[6], it is the logical federal agency to provide core support for this program. Industry participation can be through a variety of mechanisms, including the summer internship program, the advisory committees necessary for curriculum development and certification, and direct financial support of participating academic programs.

As a more general principle, we suggest that whenever such an engineering curriculum development effort is motivated primarily by national needs and priorities (e.g., nuclear energy, power systems, civil infrastructure engineering, homeland defense), then a combination of the federal government and industry should play a key role in funding the program–particularly unique components such as summer internships. On the other hand, if the disciplinary area is motivated by the excitement of a rapidly emerging area of science or technology (such as nanotechnology or biomedical engineering), then the program should be funded either by student fees or institutional reallocation (since the student credit hours associated with the minor concentration will come most likely at the expense of other electives in the engineering curriculum).

Broader Implications for Engineering Education

Today, engineering practice is evolving rapidly in response to a rapidly changing world. The shifting nature of national priorities from defense to economic competitiveness, the impact of rapidly evolving information technology, the use of new materials and biological processes—all have had deep impact on engineering practice. Put another way, the shift of our society from guns to butter, from transportation to communication, from atoms to bits, means that today's engineering students will spend most of their careers coping with challenges and opportunities vastly different from those most currently practicing engineers—or currently teaching faculty—have experienced. While engineers are expected to be well grounded in the fundamentals of science and mathematics, they are increasingly expected to acquire skills in communication, teamwork, adaptation to change, and social and environmental consciousness.

It is also clear from this perspective that engineering education simply has not kept pace with this changing environment. It is only a slight exaggeration to say that our students are currently being prepared to practice engineering in a world that existed when we, as their faculty, were trained a generation or two ago. They are not being prepared for the 21st Century.

No doubt that part of this challenge is due to the intellectual organization of the contemporary university in which academic programs are partitioned into increasingly specialized and fragmented disciplines. Perhaps reflecting the startling success of science in the 20th Century, most disciplines are reductionist in nature, focusing teaching and scholarship on increasingly narrow and specialized topics. While this produces graduates of great technical depth, it is at a certain sacrifice of a broader, more integrated education. This is particularly true in science-based disciplines such as engineering. The old saying is not far off the mark, "A Harvard graduate knows absolutely nothing about absolutely everything. An MIT graduate knows absolutely everything about absolutely nothing!"

We must question the value of narrow specialization at a time when engineering practice and engineering systems are becoming large, more complex, and involving components and processes from widely dispersed fields. Ironically enough, the essence of engineering practice is the process of integrating knowledge to some purpose. Unlike the specialized analysis characterizing scientific inquiry, engineers are expected to be society's master integrators, working across many different disciplines and fields, making the connections that will lead to deeper insights and more creative solutions, and getting things done. Thus, engineering education is under increasing pressure to shift away from specialization to a more comprehensive curriculum and broader educational experience in which topics are better connected and integrated.

As the knowledge base in most engineering fields continues to increase at an ever more rapid rate, the engineering curriculum has become bloated with technical material, much of it already obsolete. Most undergraduate engineering programs have already become almost five years in length for most students. Even with this increasing technical content, most engineers will spend many months if not years in further workplace training before they are ready for practice.

Furthermore, the effort to include the new technical knowledge in many fields, while retaining as well much of the old, has squeezed out other important curriculum content in areas.

Compounding this is the fragmentation of the current curriculum, consisting of highly specialized and generally unconnected and uncoordinated courses, whose relationship to one another and to engineering education is rarely explained. Although everyone agrees that the undergraduate curriculum should focus on the fundamentals, few can agree on just what content is truly fundamental.

It may be time to start with a clean slate by eliminating all specialized engineering majors, particularly at the undergraduate level. The ever more narrow specialization among engineering majors is driven largely by the reductionist approach of scientific analysis rather than the highly integrative character of engineering synthesis. It may be appropriate for basic research, but it is certainly not conducive to the education of contemporary engineers nor to engineering practice. Although students may be stereotyped by faculty and academic programs—and perhaps even campus recruiters—as electrical engineers, aerospace engineers, etc., they rapidly lose this distinction in engineering practice. Today's contemporary engineer must span an array of fields, such as modern technology, systems, and processes.

While the rigor of the scientific and mathematics foundation of modern engineering is important, it must be augmented by the broader contextual and integrative approach characterizing engineering practice. Students must gain experience not only in solitary analysis but also in group work and hands-on "design-build-operate" projects. We must strive to integrate real design and process understanding into the educational system. Above all, we must challenge our students to think, to create, and to understand excellence.

The curriculum model we have proposed for nuclear fission power engineering could serve as a useful model in engineering education for addressing both these general educational concerns and the more specific need for engineers trained in other highly specialized areas such as integrated manufacturing, nanotechnology, quantum engineering, and biotechnology. An undergraduate minor concentration would allow students to prepare for careers in these fields without sacrificing the broader educational experience (and market opportunities) provided by a more conventional degree program. Furthermore, by developing a curriculum and supporting materials for a minor concentration using a team of national leaders in the given specialty, colleges and universities could offer such specialized curricula without significant additional investments in new faculty and facilities. In fact, the model we propose may well represent the future of engineering education as technical knowledge continues to fragment into subdisciplinary specialties and universities face growing constraints on resources for faculty and facilities.

Conclusions

It is increasingly clear that the nation faces a serious challenge in producing the next generation of scientists and engineers necessary to support our nuclear technology needs. Even a significant reinvestment in both university nuclear engineering programs and national research in nuclear science and technology would take a decade or more to rebuild the resources necessary to respond to both industry and government needs.

We believe that our proposed undergraduate certificate program in nuclear fission power engineering has the capability of responding rapidly and effectively to meet these needs, at least on the short term basis. Furthermore, it would provide a cadre of baccalaureate degree level engineers in traditional disciplines with the additional training necessary to work in the nuclear fission technology area. Finally, it would provide a model of how a consortium of engineering programs could work together to develop and deliver a curriculum in a particular area to a broad national audience using information technology.

Here it is important to stress that this program is not intended as a replacement for traditional nuclear engineering curricula, which will continue to be necessary to meet not only national needs in nuclear fission power but in an array of other nuclear areas such as radiological physics, nuclear fusion, and nuclear security. Furthermore our national capability in nuclear technology depends critically on viable graduate programs leading to M.S. and Ph.D. degrees in nuclear engineering. Furthermore, this initiative will depend on the active involvement of faculty in existing nuclear engineering departments to develop, implement, and maintain this certificate curriculum in the future. Furthermore, the proposed curriculum is intended to complement existing undergraduate and graduate programs by providing a unique and rapidly available source of engineering graduates to meet the growing needs of industry and government in nuclear fission technology that have expanded beyond the capacity of existing programs.

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[4] Neal Todreas, Chair, "A Technology Roadmap for Generation IV Nuclear Energy Systems", Nuclear Energy Research Advisory Committee Report, U. S. Department of Energy, 2002
[5] The conventional nuclear engineering degree programs consists of 30 credits:

Atomic and nuclear physics (3)
Reactor physics (3)
Radiation effects and instrumentation (3)
Two laboratory courses in radiation measurements and reactors (4+4)
Nuclear power systems (3)
Nuclear system design (3)
Nuclear electives (e.g., shielding, fuel cycles, safety) (3)
Technical electives (4))

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